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PERSONNEL SHIELDING

by

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ABSTRACT. This report assembles and summarizes the results of tests performed on safety glass and plastic shields designed to protect personnel from the effects of detonation or explosion. Variables to be investigated in future testing are discussed.

U.S. NAVAL ORDNANCE TEST STATION
China Lake, California
September 1963

U. S. NAVAL ORDNANCE TEST STATION

AN ACTIVITY OF THE BUREAU OF NAVAL WEAPONS

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FOREWORD

This report summarizes the information on the effectiveness of safety glass and plastic personnel shields that was available to the author at the time of this study. The data herein contained will be used as the basis for a test program now under way to determine the effect of several design variables on transparent personnel shields.

The work done in this report was funded by Safety Department overhead funds and Propulsion Development Department safety overhead funds, and was carried on from October 1962 to April 1963.

The technical reviewers of this report were C. D. Lind and Jack Sherman. Other reports will follow as tests progress and new information is acquired and analyzed.

Released by
K. S. SKAAR, Head,
Safety Department
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INTRODUCTION

This is the first progress report on personnel safety shielding—that is, devices placed between hazardous material and personnel to protect them from the effects of detonation or explosion. The data summarized in the tables and graphs of this report were obtained from published reports and from limited tests conducted at the Naval Ordnance Test Station (NOTS). This source material is included in the Appendix. Since it is likely that much more testing has been accomplished and more results have been published than have been accounted for in this report, the author requests that persons knowing of such testing and publications bring this information to his attention.

SCOPE OF TESTS

So many variables affect the adequacy of the protection afforded by personnel shields that a designed experiment is needed to test these variables in order to obtain reliable information that can be applied over a wide range of conditions. Following are some of the variables that have to be studied:

1. Materials. Several types of materials are being used and have been tested to a limited extent: safety glass, tempered glass, and various plastics. Light metals and other nontransparent materials have also been used when direct viewing has not been a requirement.

2. Thickness of materials. The thickness of a shield needed to provide complete protection will have to be determined in relation to the amount of explosive and the distance of the explosive from the shield.

3. Combination and arrangement. When double-thickness shields are used, it may be advantageous to use different materials for the inner and outer shields. The difference in failure characteristics between plastic and glass will determine possible benefits to be gained by using more than one type of material in the shields. For example, laminated safety glass tends to spall before the shield fails, while plastic does not.

4. Air space. The optimum air space between the two sheets of a double-thickness shield will have to be determined. The width of this air space is important in reducing damage to the second sheet resulting from contact or interaction caused by the distortion or failure of the first sheet.

5. Fragments. The variation in the effectiveness of the shielding, with and without fragmentation of the explosive involved, must be tested. It is known that much heavier shielding is needed when explosives involving fragmentation are used than when they are not, for equivalent amounts of explosives.

6. Mounting and supporting. The type of framing and gasketing used for mounting the shields will be of importance in the protection offered, and the method used for supporting the assembly should be investigated. Some of the tests have shown that stresses caused by poor mounting of the sheets results in cracking and failure during less severe conditions. Also, when mounting is accomplished by inserting bolts through holes in the shielding material, cracking occurs at these bolt holes before it occurs in the main body of the shield.

TEST RESULTS

An effort has been made to summarize the test data contained in the Appendix so as to make them more meaningful and more useful. However, there are not sufficient data in most instances, and conditions under which various sets of data were obtained were not sufficiently designed or controlled to permit good direct correlation of the data. Some of the tests were run under specific conditions for particular ordnance items, many tests varied as to the type and amount of fragmentation involved, and there was also considerable difference in the mounting of the shields. The test results summarized in the tables and graphs involve many of these variables but are grouped together to provide sufficient points from which to launch a proposal for needed information.

Table 1 lists the results of the tests in which only one thickness of Plexiglas was used as a shield. Figure 1 is a graph of these results. Straight lines are drawn between points offering protection for each thickness of shield. This is probably not a straight-line function, but in most instances only two points were available. These lines should not be used as guides due to the limited values from which they were determined. It is interesting to note that all failures recorded are to the left of or above the corresponding line, as they should be if the lines drawn represent a level at which complete protection can be expected. Figure 2 shows the curves for tests involving 25 and 50 grams of explosives using various thicknesses of Plexiglas at various distances. Again failures are in the right relationship—in this case, below or to the left of the curve.

Table 2 lists the results of the tests in which a double-thickness Plexiglas shield was used. Figure 3 is a graph of these test results. The values used for thickness in the graph are the sum of the thicknesses of the two sheets of Plexiglas; sufficient data were not available

TABLE 1. PROTECTION AFFORDED BY SINGLE-THICKNESS PLEXIGLAS

All shields were about 12 by 18 inches, except as noted.

Thickness of shield, in.	Weight of explosives, g	Distance of explosives from shield, in.	
		Shield gave protection	Shield failed
1/4	5	6	....
	25	30	....
3/8	7 1/2	8	5
	25	13 1/2	....
	50	26	....
1/2	20	....	4
	25	12[a]	10[a]
	50	15	12[b]
1	20	2	....
	50	10	....
	100	....	12

[a] 30 by 16 1/2 inches.
[b] 36 by 48 inches.

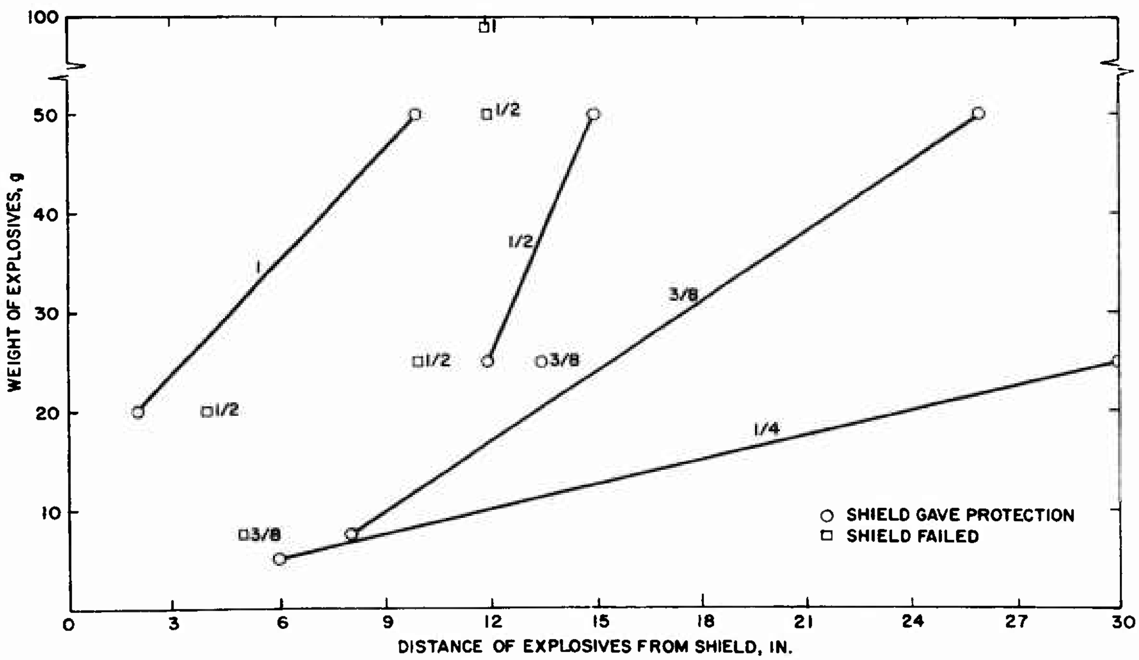

FIG. 1. Test Results of Single-Thickness Plexiglas Shields. All values in inches.

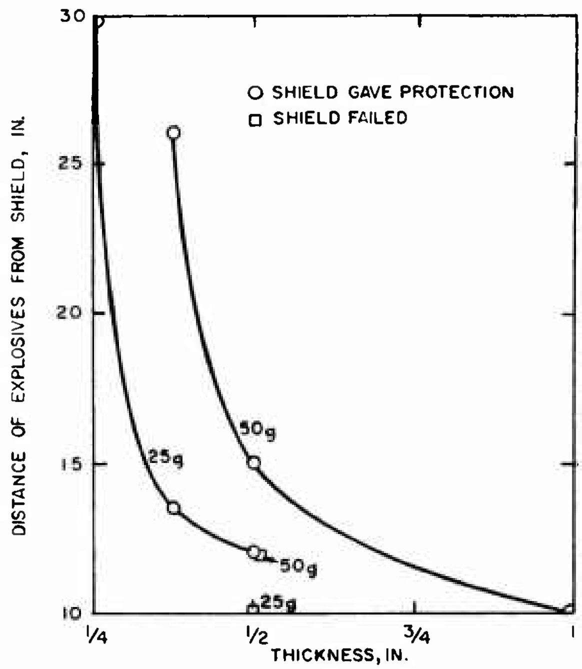

FIG. 2. Test Results of Single-Thickness Plexiglas Shields Subjected to Detonations of 25 and 50 Grams of Explosives.

TABLE 2. PROTECTION AFFORDED BY DOUBLE-THICKNESS PLEXIGLAS

All shields were about 12 by 18 inches, except as noted. In cases where sheets were of different thicknesses, the thicker sheet was on the side closest to the explosive charge.

Thickness of shield, in.		Air space, in.	Weight of explosives, g	Distance of explosives from shield, in.	
Individual	Total			Shield gave protection	Shield failed
1/4 + 1/4	1/2	4	25	....	6[a]
		unknown	50	20	....
1/4 + 1/2	3/4	1/4	20	4	2
3/8 + 3/8	3/4	unknown	50	12	....
1/2 + 1/2	1	1/4	50	7	....
1/4 + 1	1 1/4	1/4	20	2	1/2
		1/4	50	8	....
		1/4	100	12	....
3/8 + 1	1 3/8	1	50	6	....
1/2 + 1	1 1/2	0	50	....	6
1/4 + 1 1/2....	1 3/4	1/4	100	....	8
4 + 4[b]..............	8	6	1,068	24	....

[a] 32 by 22 inches.
[b] These shields tapered from 27 1/2 by 27 1/2 to 10 by 10 inches.

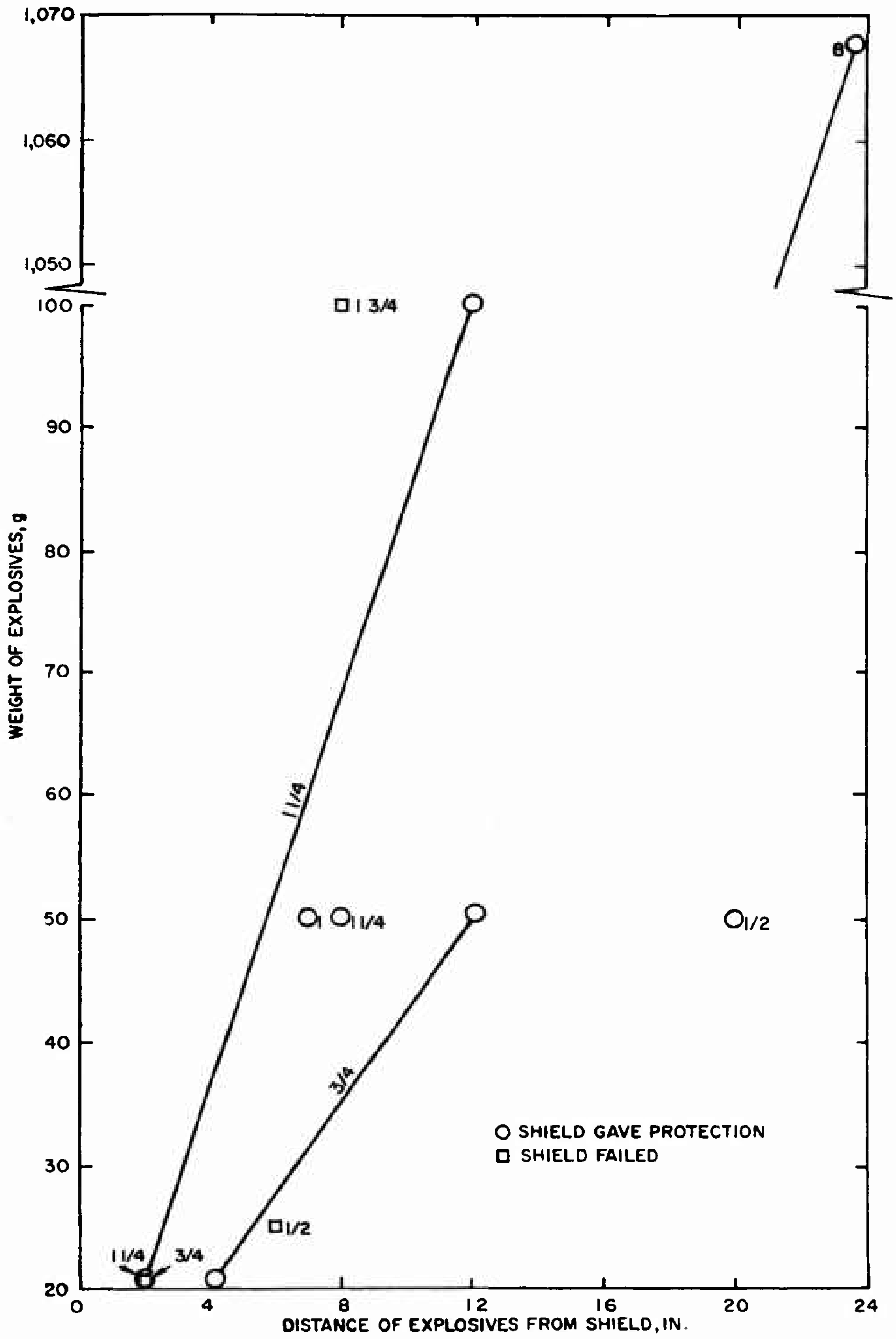

FIG. 3. Test Results of Double-Thickness Plexiglas Shields. All values in inches of total thickness.

to present the information by thicknesses of the individual sheets. The air space between the two sheets in most cases was 1/4 inch.

Very little data were obtained from tests using laminated safety glass (Table 3). In Fig. 4 sufficient data for a line were available only for 1/4-inch-thick two-ply laminated safety glass.

Figure 5 compares the results of the tests on the 1/4-inch Plexiglas and laminated safety glass shields.

Table 4 lists results for tests in which a single thickness of Lucite was used. Figure 6 is a graph of these results as they apply only to 18 grams of explosives.

TABLE 3. PROTECTION AFFORDED BY LAMINATED SAFETY GLASS

Thickness of of shield, in.	No. of plies	Weight of explosives, g	Distance of explosives from shield, in.	
			Shield gave protection	Shield failed
1/4	2	5	10 1/4	....
	2	7 1/2	12	8
	2	25	17 1/2	....
3/4	2	18	6	5
	3	18	2	1
	4	18	1	0

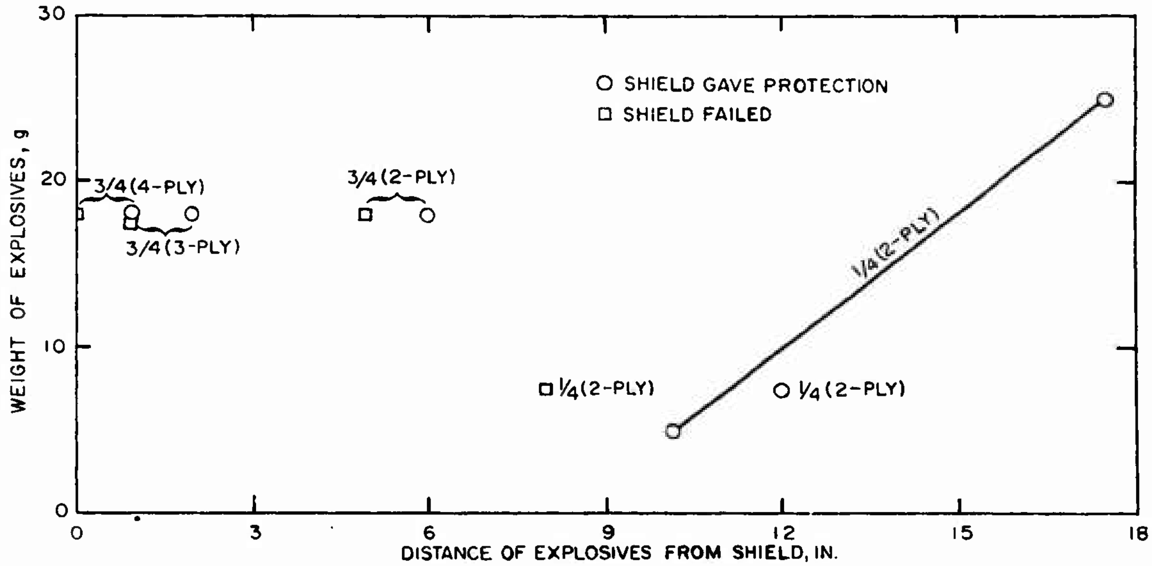

FIG. 4. Test Results of Laminated Safety Glass Shields. All values in inches.

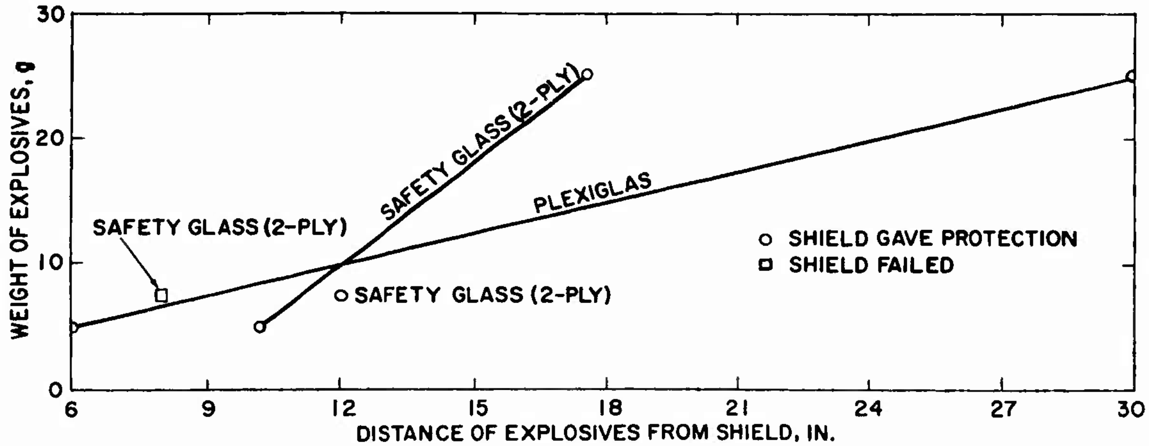

FIG. 5. Comparison of Test Results of 1/4-Inch Plexiglas and Laminated Safety Glass Shields.

TABLE 4. PROTECTION AFFORDED BY SINGLE-THICKNESS LUCITE

Thickness of shield, in.	Weight of explosives, g	Distance of explosives from shield, in.	
		Shield gave protection	Shield failed
1/4	18	....	12
1/2	18	5	4
3/4	18	3	2
1	18	2	1
	36	....	12

Table 5 lists the test results by quantity of explosives.

Table 6 lists results for tests in which a single thickness of Butecite-cored Lucite was used.

Reference 1 compares some of the properties of various window materials. Table 7 includes comparisons, for pertinent properties, of some of the materials for which test results have been included in this report.

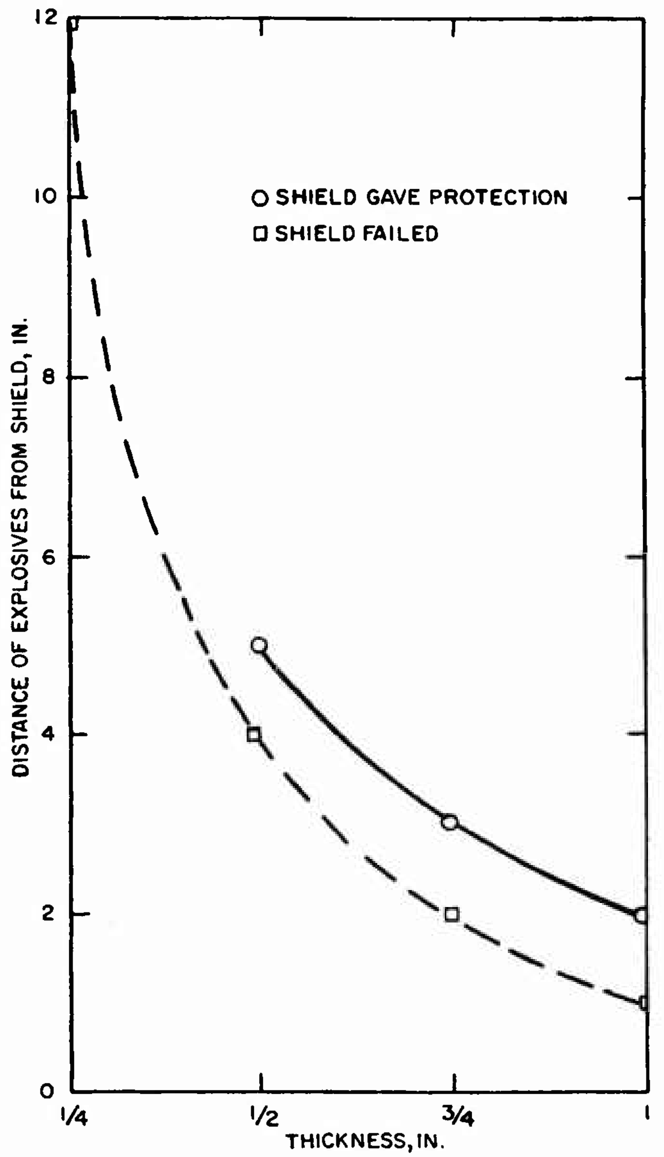

FIG. 6. Test Results of Single-Thickness Lucite Shields Subjected to Detonations of 18 Grams of Explosives.

TABLE 5. TESTS LISTED BY QUANTITY OF EXPLOSIVE USED

Explosives weighing over 100 grams are not included.

Weight of explosives, g	Shield		Distance of explosives from shield, in.	
	Material	Thickness, in.	Shield gave protection	Shield failed
5	safety glass	1/4 (2-ply)	10 1/4	....
	Plexiglas	1/4	6	....
7 1/2	safety glass	1/4 (2-ply)	12	8
	Plexiglas	3/8	8	5
18	Lucite	1/4	....	12
	safety glass	3/4 (2-ply)	6	5
	Lucite	1/2	5	4
	Lucite	3/4	3	2
	Lucite	1	2	1
	safety glass	3/4 (3-ply)	2	1
	safety glass	3/4 (4-ply)	1	0
20	Plexiglas	1/2	....	4
	Plexiglas	1/4 + 1/2	4	2
	Plexiglas	1	2	....
	Plexiglas	1/4 + 1	2	1/2
25	Plexiglas	1/4	30	....
	safety glass	1/4 (2-ply)	17 1/2	....
	Plexiglas	3/8	13 1/2	....
	Plexiglas	1/2	12	10
	Plexiglas	1/4 + 1/4	....	6
36	Lucite	1	....	12
50	Plexiglas	3/8	26	....
	Plexiglas	1/4 + 1/4	20	....
	Plexiglas	1/2	15	12
	Plexiglas	3/8 + 3/8	12	....
	Plexiglas	1	10	....
	Plexiglas	1/4 + 1	8	....
	Plexiglas	1/2 + 1/2	7	....
	Plexiglas	1 1/2	....	6
	Plexiglas	3/8 + 1	6	....
100	Plexiglas	1	....	12
	Plexiglas	1/4 + 1	12	....
	Plexiglas	1/4 + 1 1/2	....	8

TABLE 6. PROTECTION AFFORDED BY BUTECITE-CORED LUCITE

Thickness of shield, in.	Weight of explosives, g	Distance of explosives from shield, in.	
		Shield gave protection	Shield failed
1/2	18	3	2
5/8	18	3	2
	22	6	....
	36	....	12

TABLE 7. PROPERTIES OF MATERIALS

Material	Clarity	Ease of fabrication	Resistance		
			Fire	Heat	Impact
Laminated safety glass	excellent	fair	excellent	very good	good
Plexiglas 5009 (flame resistant)	very good	good	very good	poor (125° F)	good
Plexiglas (flammable)	very good	excellent	poor	good (200° F)	very good
Lucite	very good	excellent	poor	good (200° F)	very good

CONCLUSIONS

There is not sufficient information available at present to formulate specific guidelines for providing adequate shielding for personnel protection, except for a very few applications. Indeed, it is emphasized that the graphs and tables contained in this report should not be used as guides in setting up personnel protection, since they have been derived from a limited amount of data that involve many variables that prohibit accurate correlation. It is apparent that there is a need for a test program to obtain the considerable amount of additional information that is lacking. Such a program has already been initiated at NOTS.

Appendix

SOURCE DATA FOR TEST SUMMARIES[1]

The data in this appendix, which comprise Tables 8—12 and other tabular and descriptive matter, come from published reports and from limited tests conducted at NOTS, and are summarized in the tables and graphs in the body of this report.

TABLE 8. PROTECTION AFFORDED BY PLEXIGLAS WINDOWS (REF. 2)[a]

OK indicates that the sheet remained intact after the explosion, M that the sheet remained intact but was badly pitted, NG that the fragments were blown through the window.

Thickness of Plexiglas, in.	Distance of explosion from window, in.	Explosive charge, Composition C-4		
		20 grams	50 grams	100 grams
1/4 + 1 1/2	8	.....	.....	NG
1/4 + 1	1/2	NG	.....	.....
	2	OK	.....	.....
	4	OK	.....	.....
	8	OK	OK	NG
	12	OK	OK	OK
1	2	M	.....	.....
	4	OK	.....	.....
	8	OK	NG	.....
	10	.....	OK	.....
	12	OK	OK	NG
1/2 + 1/2	7	.....	OK	.....
1/4 + 1/2	2	NG	.....	.....
	4	OK	.....	.....
1/2	4	NG	.....	.....
	15	.....	OK	.....

NOTE: Metal fragments were produced in all tests. Twelve- by 18-inch windows were used. When two sheets were used they were separated by a 1/4-inch air space; the thicker sheet faced the explosion.

[a] Although Ref. 2 is Confidential, the information contained in this table is Unclassified.

[1] The author has rearranged the source data for reasons of presentation but has not altered the data in any way.

In each of the three following tests (Ref. 3) a box of fifty M20 detonators (approximately 18 grams of explosives) was used, except as noted.

TABLE 9. PROTECTION AFFORDED BY LUCITE

Shield, 12 by 20 inches, approximately 70 degrees from the horizontal.

Thickness of shield, in.	Distance of explosives from shield, in.	Results
1	2	No damage
	1	Blown into 10 large fragments
	12[a]	Blown into eight large fragments
3/4	3	No damage
	2	Cracked into two pieces
1/2	5	No damage
	4	Blown into large fragments
	0	Blown into pieces to a distance of 20 feet
1/4	12	Blown into approximately 25 small pieces

[a] 100 detonators used.

TABLE 10. PROTECTION AFFORDED BY BUTECITE-CORED LUCITE

Thickness of shield, in.	Distance of explosives from shield, in.	Results
1/2	4	Slight cracks at bolt holes
	3	Slight cracks at bolt holes
	2	Several large cracks but shield not fragmented
5/8	12	No damage
	9	Slight cracks at bolt holes
	5	Slight cracks at bolt holes
	4	Long cracks from bolt holes
	3	No damage
	2	Large cracks, but shield intact
	6[a]	Slight cracks at bolt holes
	12[b]	Large cracks throughout, but shield remained intact

[a] 62 detonators used.
[b] 100 detonators used.

TABLE 11. PROTECTION AFFORDED BY SAFETY GLASS

Shield is 3/4-inch thick.

No. of plies	Distance of explosives from shield, in.	Results
4	4	Slight pitting of back face
	3	Slight pitting of back face
	2	Back face pitted and cracked
	1	Front face cracked, no spalling
	0	6- by 3-inch hole through first ply; some spalling from front face; no penetration
3	4	Slight pitting of back face
	3	Slight pitting of back face
	2	Front face cracked
	1	Few loose pieces fell out of front face
	0	8- by 4-inch hole through first ply; spalling from front face
2	8	Both layers of glass cracked
	6	Both layers of glass cracked
	5	Both layers of glass cracked; sand-sized pieces spalled from front
	4	Severe cracking both faces; two pieces 1/4- by 1/2-inch spalled to 3 inches from front face

Table 12 and the three following text tables are derived from Ref. 4.

TABLE 12. CONDITIONS UNDER WHICH VARIOUS MATERIALS AFFORD COMPLETE PROTECTION

Material	Distance of shield, in., from explosives weighing—		
	5 grams	25 grams	50 grams
1/4-inch safety glass	10 1/4	17 1/2	...
1/4-inch Plexiglas	6	30	...
3/8-inch Plexiglas	....	13 1/2	26
Double 1/4-inch Plexiglas; air space	....	....	20
Double 3/8-inch Plexiglas; air space	....	....	12
3/4-inch plywood	....	....	26
3/4-inch oak board	....	12	30
3/4-inch pine board	....	30	...
24-gage sheet metal	....	30	...
14-gage sheet metal	....	....	6
1/4-inch plywood backed with 24-gage sheet metal	....	6	...
1/2-inch plywood backed with 24-gage sheet metal	....	....	6

Two 12- by 18-inch double-thickness Plexiglas shields were subjected to an explosion of 50 grams of Composition C-4 at a distance of 6 inches. The results follow:

Thickness of shield, in.	Air space, in.	Results
1 + 1/2	0	Failed
1 + 3/8	1	Protected: 1-inch plate broke; 3/8-inch plate did not

Single-thickness Plexiglas shields of different dimensions were subjected to an explosion of 25 grams of Composition C-4 that was contained in a glass bottle. The results follow:

Thickness of shield, in.	Dimensions, in.	Frames	Distance of explosives from shield, in.	
			Shield gave protection	Shield failed
1/2	30 1/2 by 14 1/2	light aluminum	....	8
			10	10
1/2	30 by 16 1/2	light-aluminum channel	10 (marginal)	....
			12 (good)	....

Single- and double-thickness Plexiglas shields suspended from a ceiling were subjected to explosions of various quantities of Composition C-4. The results follow:

Thickness of shield, in.	Dimensions, in.	Weight of explosives, g	Distance of explosives from shield, in.	
			Shield gave protection	Shield failed
1/4	32 by 22	5 (in glass bottle)	6	....
1/4 + 1/4	32 by 22	25	....	6
1/2	36 by 48	50	....	12

The following summary is derived from Ref. 5.[2]

Two 4-inch-thick panes of Plexiglas were mounted in a 15-inch-thick reinforced concrete wall and were separated by a 6-inch air space. The inner pane was 27 1/2 inches square and its bay side tapered to 20 1/2 inches square. The outer pane was 10 inches square at the outer face of the wall.

[2] Although Ref. 5 is Confidential, this summary is Unclassified.

An Arcocel-type solid-propellant formulation was used in a 1/2-pound uncased charge, a 1-pound uncased charge, and a 2-pound cased charge. The uncased charges were cast in a 2-inch-diameter cardboard tube. The cased charge was cast in a lightweight steel tube that had a 2 3/4-inch outside diameter, a 6 2/5-inch length, and a 1/10-inch wall thickness. The three charges were initiated by an Engineers Special Blasting Cap with two tetryl pellets (about 160 grams). The results of the three tests follow:

1. Test No. 1. The 1/2-pound uncased charge was located 2 feet from the lower edge of the window. The total weight of the charge was 0.85 pound. Three pits, 1/4 to 3/8 inch in diameter by about 1/8 inch deep, plus a few scattered smaller pits appeared in the Plexiglas face. Four screw heads were broken off the bottom steel window frame.

2. Test No. 2. The 1-pound uncased charge was also located 2 feet from the lower edge of the window. The total weight of the charge was about 1.35 pounds. Three additional pits about the size of those in Test No. 1 appeared plus scattered small pits.

3. Test No. 3. The 2-pound cased charge was placed in the same location as the others. The total weight of the charge was about 2.35 pounds. The inner piece of Plexiglas was cut by shrapnel sufficiently to sever it, so that about three-quarters of the pane fell onto the floor. The retaining bolts along both sides of the window and the bottom of the steel window frame were completely loosened.

The three following text tables were compiled from an unpublished report[3] on tests of laboratory safety shields conducted at NOTS.

Several 1/4-inch single-thickness safety glass shields were subjected to an explosion of 5 grams of Composition B plus 2 1/2 grams of tetryl. The results follow:

Distance of explosives from shield, in.	Results
15	Small cracks
12	Large cracks
8	Cracks; spalling from opposite side of shield
5	Shield failed; hole appeared

Two 3/8-inch single-thickness Plexiglas shields were subjected to an explosion of 5 grams of Composition B plus 2 1/2 grams of tetryl. The results follow:

[3] By C. D. Lind, Propulsion Development Department, NOTS, September 1957.

Distance of explosives from shield, in.	Results
8 (and farther)	No effect
5	Shield broke in two

A 1/4-inch double-thickness Plexiglas shield, separated by a 1/4-inch air space, was subjected to explosions of various quantities of PBXN-1 plus 2 1/2 grams of tetryl at a distance of 8 inches. The edges of the shield were reinforced with 1/8- by 3/4-inch aluminum strips. The results follow:

Weight of PBXN-1, g	Results
4.35	No effect
5	Small crack in one side
10	Enlarged crack in one side
15	Small crack in opposite side; no change in existing crack

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Personnel Shielding, by Paul A. Donaldson, China Lake, Calif., NOTS, September 1963. 18 pp. (Technical Progress Report 326, NOTS TP 3287), UNCLASSIFIED.

ABSTRACT. This report assembles and summarizes the results of tests performed on safety glass and plastic shields designed to protect personnel from the effects of detonation or explosion. Variables to be investigated in future testing are discussed.

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